



Evolvable Mars Campaign Small Habitat Commonality Reduces Cost and Improves Operations

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Future In-Space Operations Colloquium

July 29, 2015

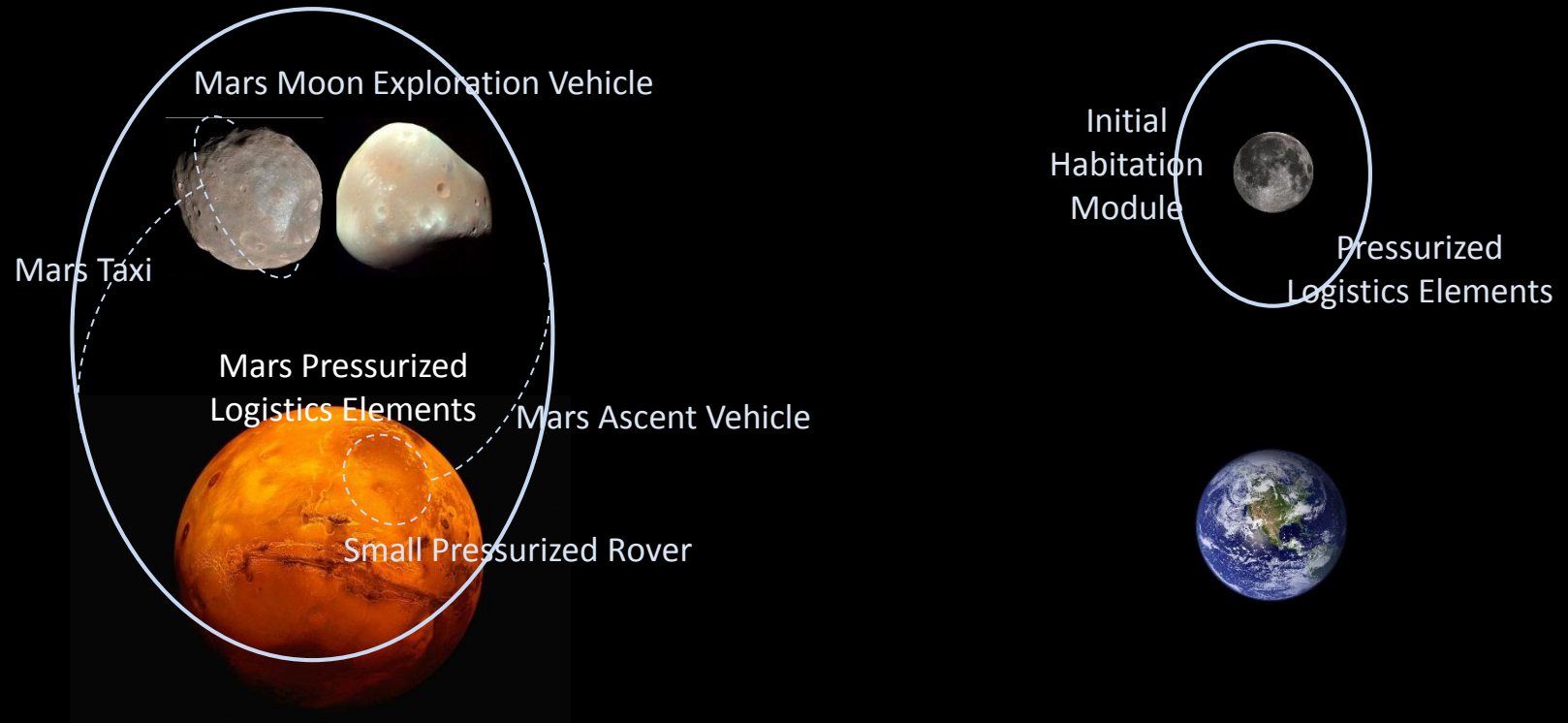
<http://spirit.as.utexas.edu/~fiso/archivelist.htm>





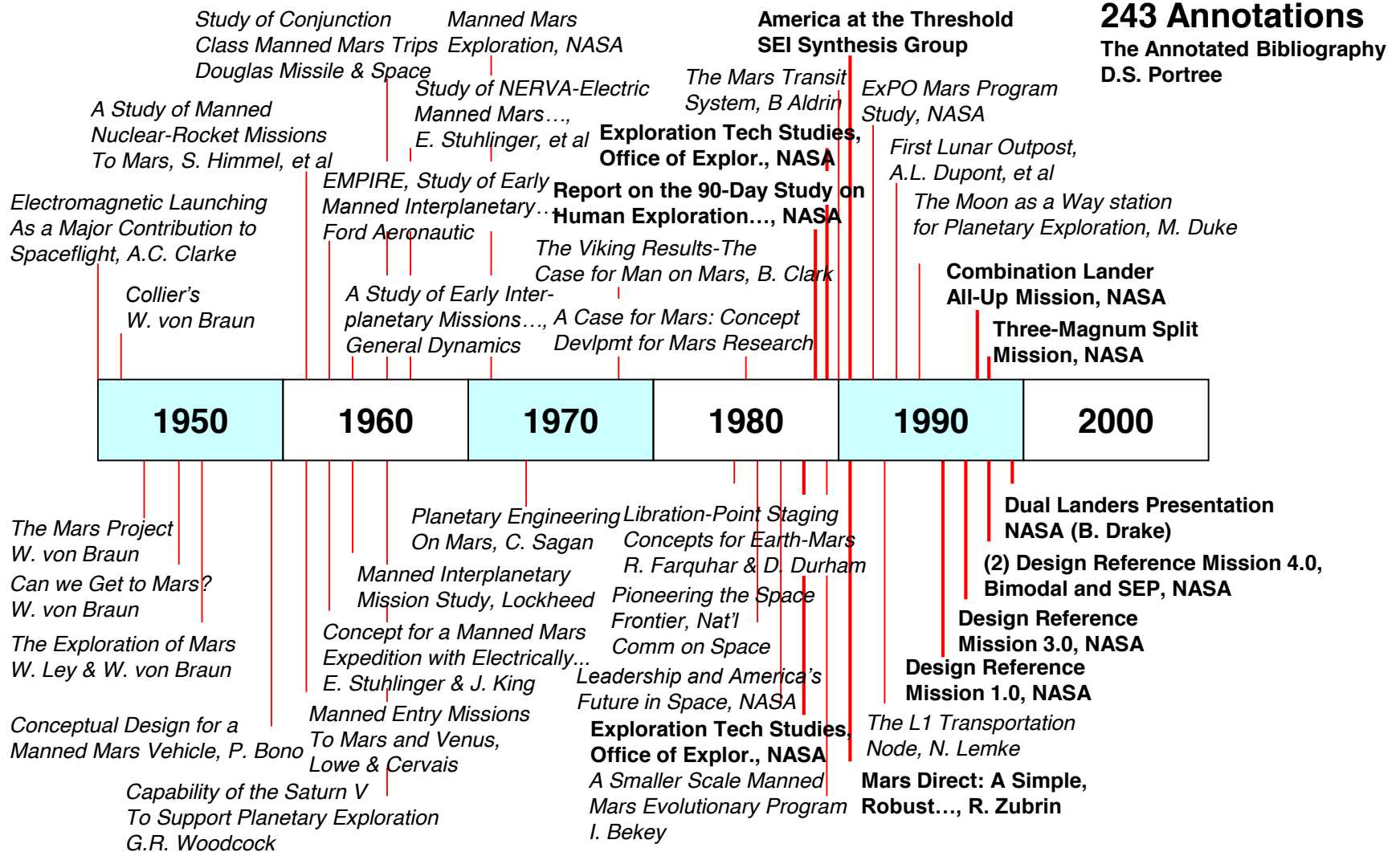
- **The Small Habitat Commonality work is part of NASA's Evolvable Mars Campaign (EMC) *Doug Craig FISO***
- **EMC First Three Missions**
 - **Human mission to Phobos *Mike Gernhardt FISO***
 - **Followed by two long stay (500 day) Mars surface missions**
- **This material responds to the question of :
How to maximize commonality across the small habitats**
- **Approximately 8 months with a part-time, multi-center team**
- **Results: Created tools to quantify commonality cost savings early in the planning process. ~\$ 3-4B LCC with commonality**

EMC Small Habitat Commonality Scope




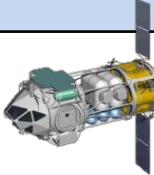




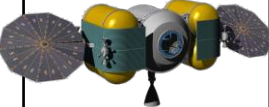



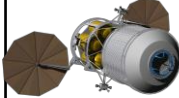

Many Mars Studies

Many Small Habitats



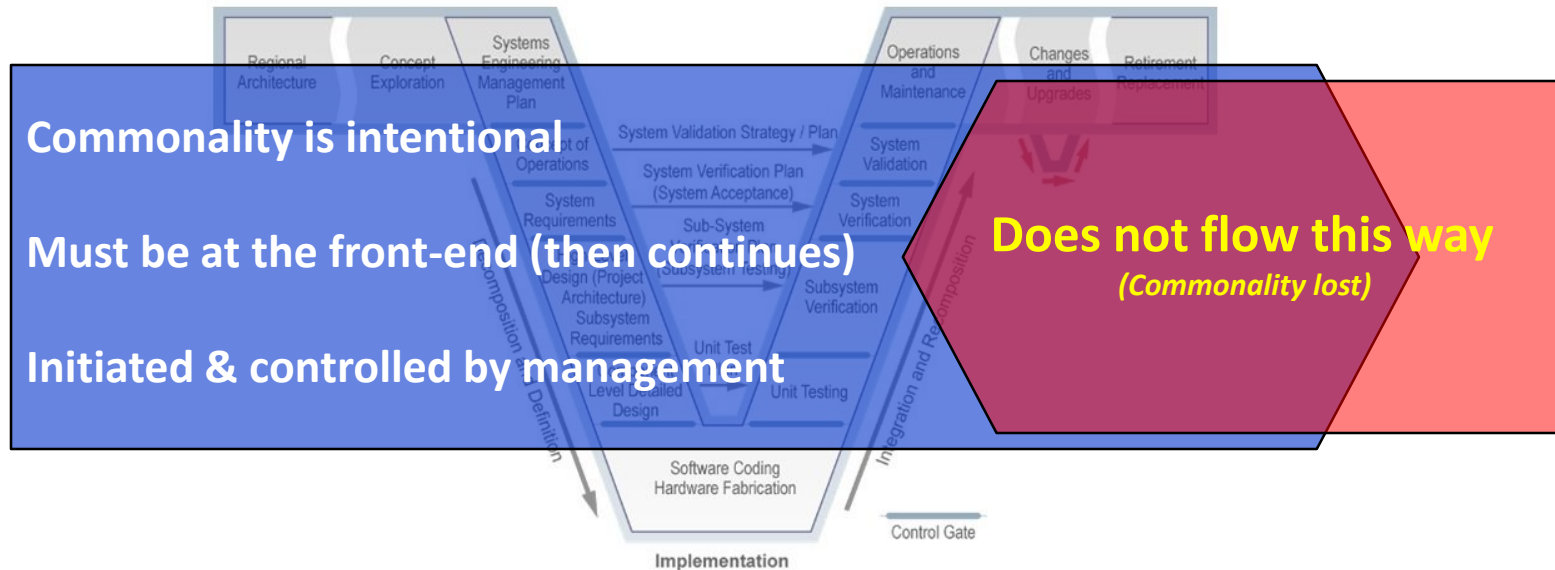
EMC Small Habitat Commonality



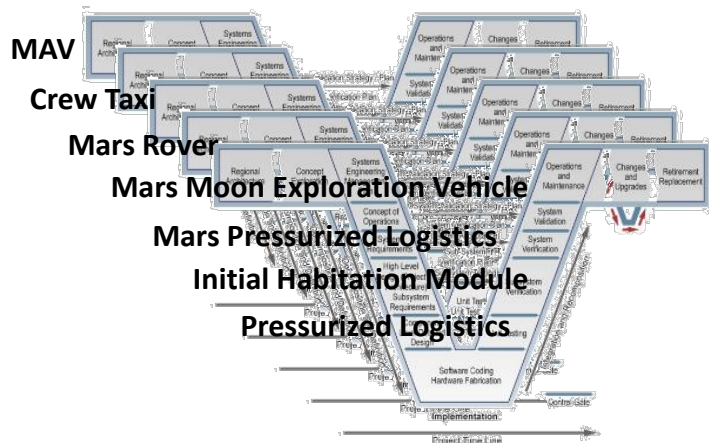
	Mars Ascent Vehicle	Mars Moon Taxi	Mars Moon Exploration Vehicle	Mars Rover	Mars Logistics Module	EAM	EAM Logistics
Before Commonality						Not Included	Not Included
EMC Commonality							
Crew Size	4	4	2	2	0	2-4	0
Duration	1.8 da (44 hrs)	3.2 da (77 hrs) 1 Sol-Phobos-Deimos-1Sol	14 days (max)	14 days (max)	Temporary access	14 days (max)	Temporary access
Reuse	Disposable	Disposable	Disposable	Reusable	Disposable/Repurpose	Reusable	Disposable/Repurpose
Environment	Mars surface, Mars Orbit	Mars Orbit	Mars Moon	Mars surface	Mars surface (possible orbit)	Cis lunar orbit	Cis lunar orbit
EVA	No EVA	One way transport 4 suits to Mars moon	Micro-g (suitport)	Mars surface (suitport)	No EVA	Attached Micro-g Airlock	No EVA

Commonality: Lead From the Start and Never Stop

Program Development

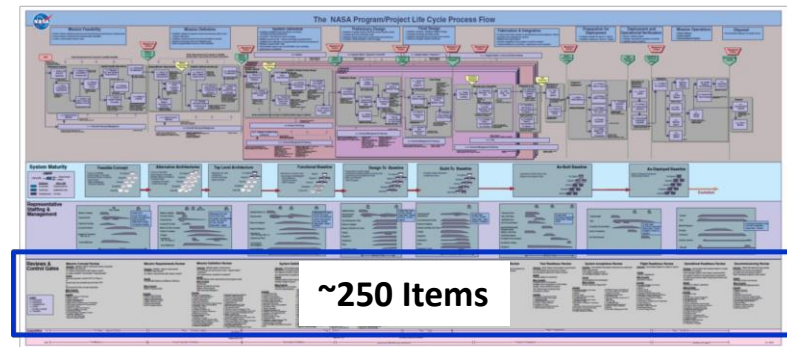


Unique DDT&E



NASA Program DDT&E

Mars Small Habitats will Use NASA Program/Project Life Cycle Process



Advantages/Disadvantages of Commonality



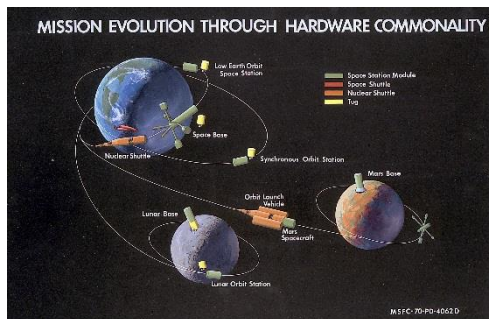
Advantages

- Reduced cost (one vs. multiple DDT&E)
- Improved safety (common operations)
- Interoperability
- Reduced logistics (same spares for different habitats)
- Simplified infrastructure integration (one interface vs. multiple)
- Simplified training (one system vs. multiple)

Disadvantages

- Sub-optimized (each application usually gives up unique attributes)
- May preclude inclusion of latest technology

1970s Commonality



Space Station Common Module



Inter-modal Cargo Container



Major Elements of Commonality



Physical

Size, Geometry,
Subsystems, etc.

Functional

Operations,
power, data, etc.

Acquisition

Procurement,
DDT&E, life-cycle

Management

Implementing
recommendations

Highest

Commonality Index

- 5 Identical
- 4 Similar (most subsystems)
- 3 Similar (many subsystems)
- 2 Similar (some subsystems)
- 1 Similar (few subsystems)
- 0 Unique

Single

Gov Furnished Equip

Build to Print

Multiple

Report to Prog Mgr (safety)

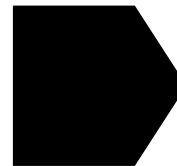
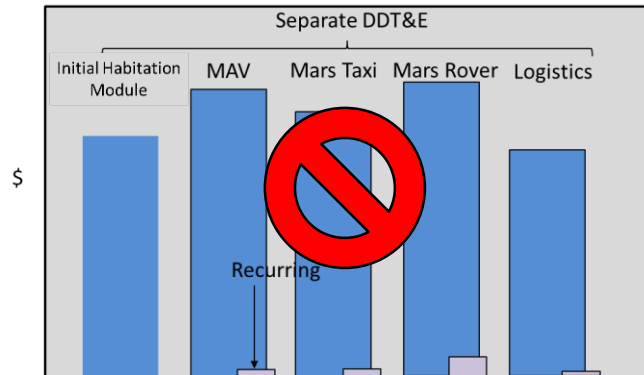
Line Mgr

Document w/o Mgr

Objective: Maximize Small Habitat Commonality

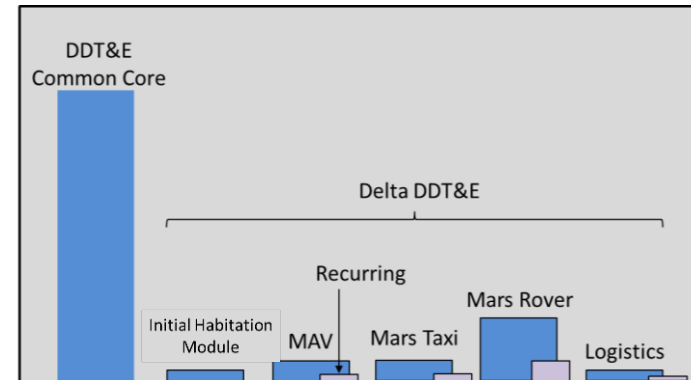


Without Commonality (Separate Parallel Development)



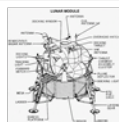
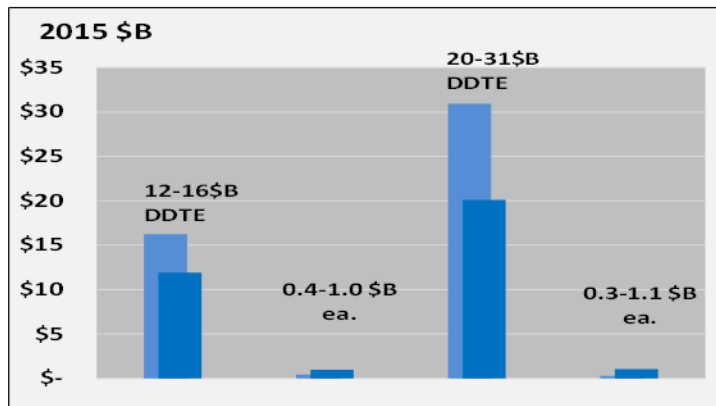
Commonality Objective

(Single Major Development with Small Delta Developments)



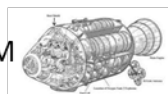
Analogous Program DDT&E and Recurring Unit Manuf.\$

-Manufacturing Rates 2-3/year-

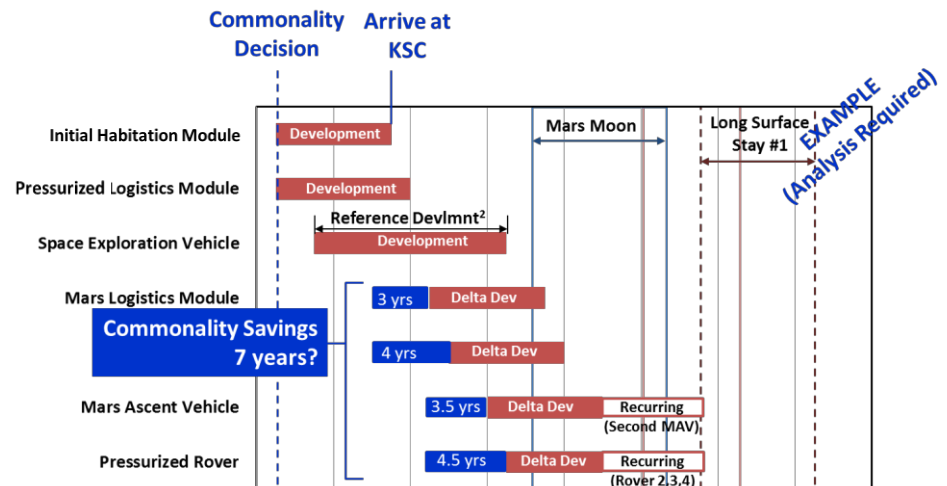


LEM

CSM



Reduced Program Schedule



Creating a Core Commonality

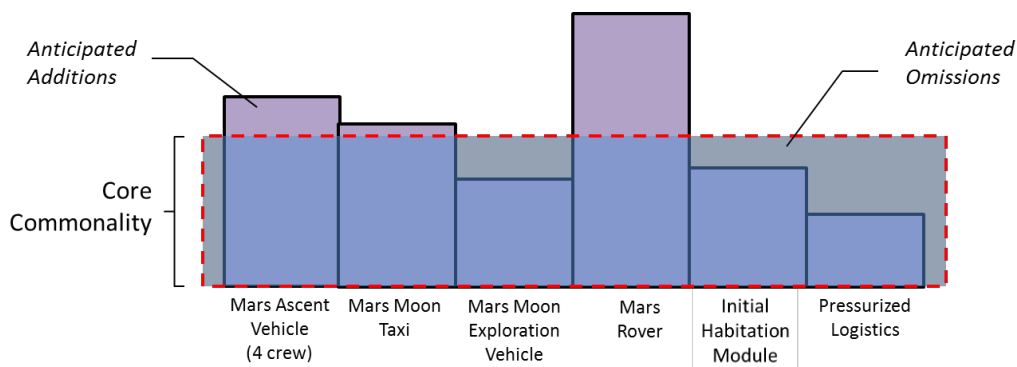


Commonality Assessment Tool

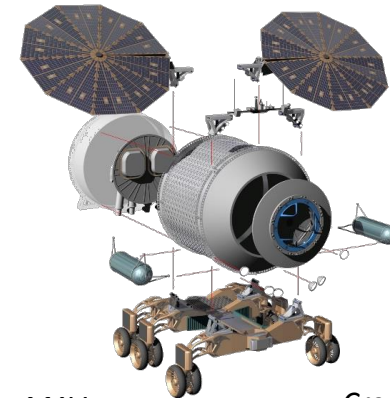
Based on Master Equipment List Comparison

Subsystems	Components	Element Functionality	Mass by Habitat	Mass Difference (Compared to most inclusive)
HABITAT STRUCTURE	HABITAT EQUIPMENT SUMMARY	MAV ASSENT VEHICLE HABIT	MAV ASSENT VEHICLE HABIT	MAV ASSENT VEHICLE HABIT
1	PRELUSURE VESSEL	0.1	1700.0	0.0
2	INTERFACE, DOORING	0.1	0.0	0.0
3	DOCKING HATCHES	0.1	0.0	0.0
4	SEPARATION COMPONENTS/MECHS	0.1	0.0	0.0
5	OBSERVATION WINDOWS	0.1	0.0	0.0
6	DOCKING WINDOWS	0.1	0.0	0.0
7	PVA HATCHES	0.1	0.0	0.0
8	ELECTRICAL POWER SYSTEM	0.1	0.0	0.0
9	POWER MANAGEMENT CONTROL EQUIPMENT INCL. INSTAL.	0.1	0.0	0.0
10	DISTRIBUTED POWER BUSES/CABLES (POWER SOURCES TO LOADS)	0.1	0.0	0.0
11	SOLAR PANELS INCL. INSTALLATION	0.1	0.0	0.0
12	BATTERIES INCL. INSTALLATION	0.1	0.0	0.0
13	FUEL CELLS INCL. INSTALLATION	0.1	0.0	0.0
14	FUEL CELL REACTANT STORAGE TANKS, FLUID DISTRIB. & INSTALLATION	0.1	0.0	0.0
15	COMMAND & DATA HANDLING SYSTEMS	0.1	0.0	0.0
16	CEPH CABLES/DATA BUSES (PLT CRITICAL SYS MGMT)	0.1	0.0	0.0
17	VIDEO PROCESSING EQUIPMENT INCL. INSTALLATION	0.1	0.0	0.0
18	NETWORK CONTROL EQUIPMENT INCL. INSTALLATION	0.1	0.0	0.0
19	RECORDERS INCL. INSTALLATION	0.1	0.0	0.0
20	FLIGHT COMPUTER INCL. INSTALLATION	0.1	0.0	0.0
21	DISTRIBUTED CONTROL EQUIPMENT INCL. INSTALLATION	0.1	0.0	0.0
22	DISPLAYS, CONTROLS & LIGHTS	0.1	0.0	0.0
23	DISPLAY & CONTROL EQUIPMENT INCL. INSTALLATION	0.1	0.0	0.0
24	INTERNAL CABIN LIGHTS INCL. INSTALLATION	0.1	0.0	0.0
25	EXTERNAL LIGHTS ILLUMINATION INCL. INSTALLATION	0.1	0.0	0.0
26	EXTERNAL LIGHTS ILLUMINATION INCL. INSTALLATION	0.1	0.0	0.0
27	EXTERNAL LIGHTS ILLUMINATION INCL. INSTALLATION	0.1	0.0	0.0
28	EXTERNAL LIGHTS ILLUMINATION INCL. INSTALLATION	0.1	0.0	0.0
29	EXTERNAL LIGHTS ILLUMINATION INCL. INSTALLATION	0.1	0.0	0.0
30	EXTERNAL LIGHTS ILLUMINATION INCL. INSTALLATION	0.1	0.0	0.0

Core Commonality



Commonality Validation

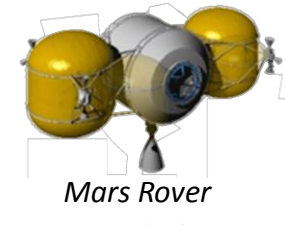


MAV

Crew Taxi



Exploration Vehicle



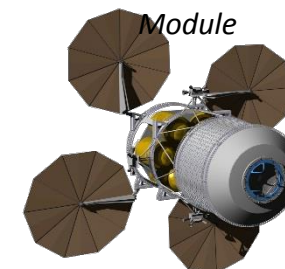
Mars Rover



Initial Habitation Module



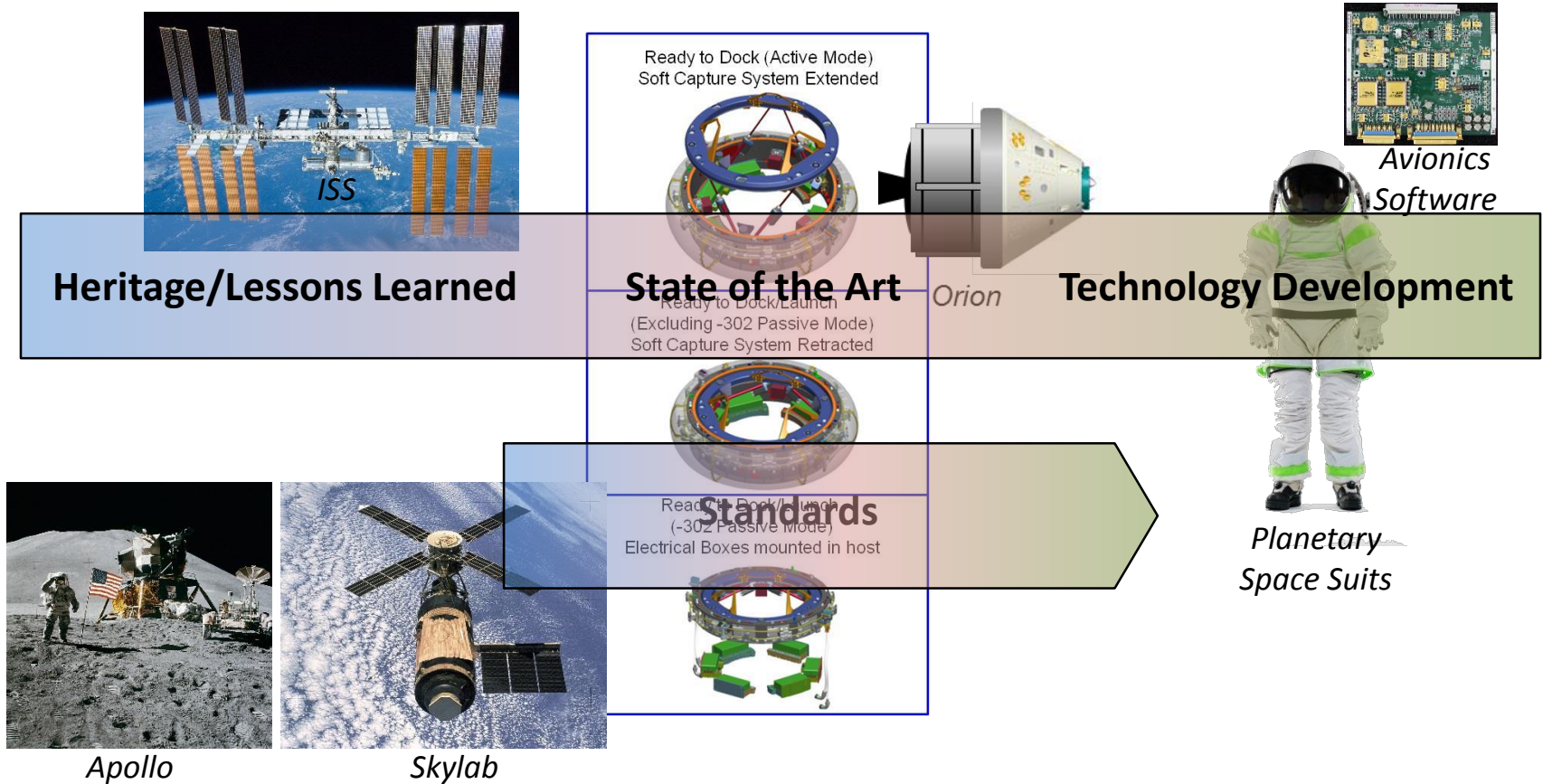
Pressurize Logistics



Commonality: Heritage + New



Breadth



Commonality Acquisition and Management



Boeing 757

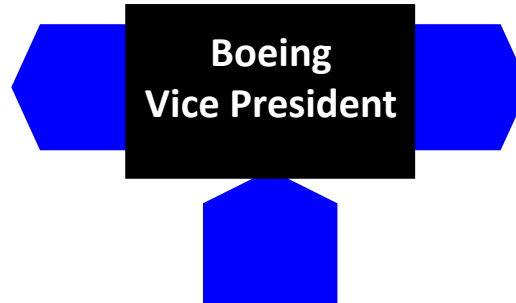


Narrow body 3.54 m

Boeing 767



Wide body 5.03 m



Common Cockpit



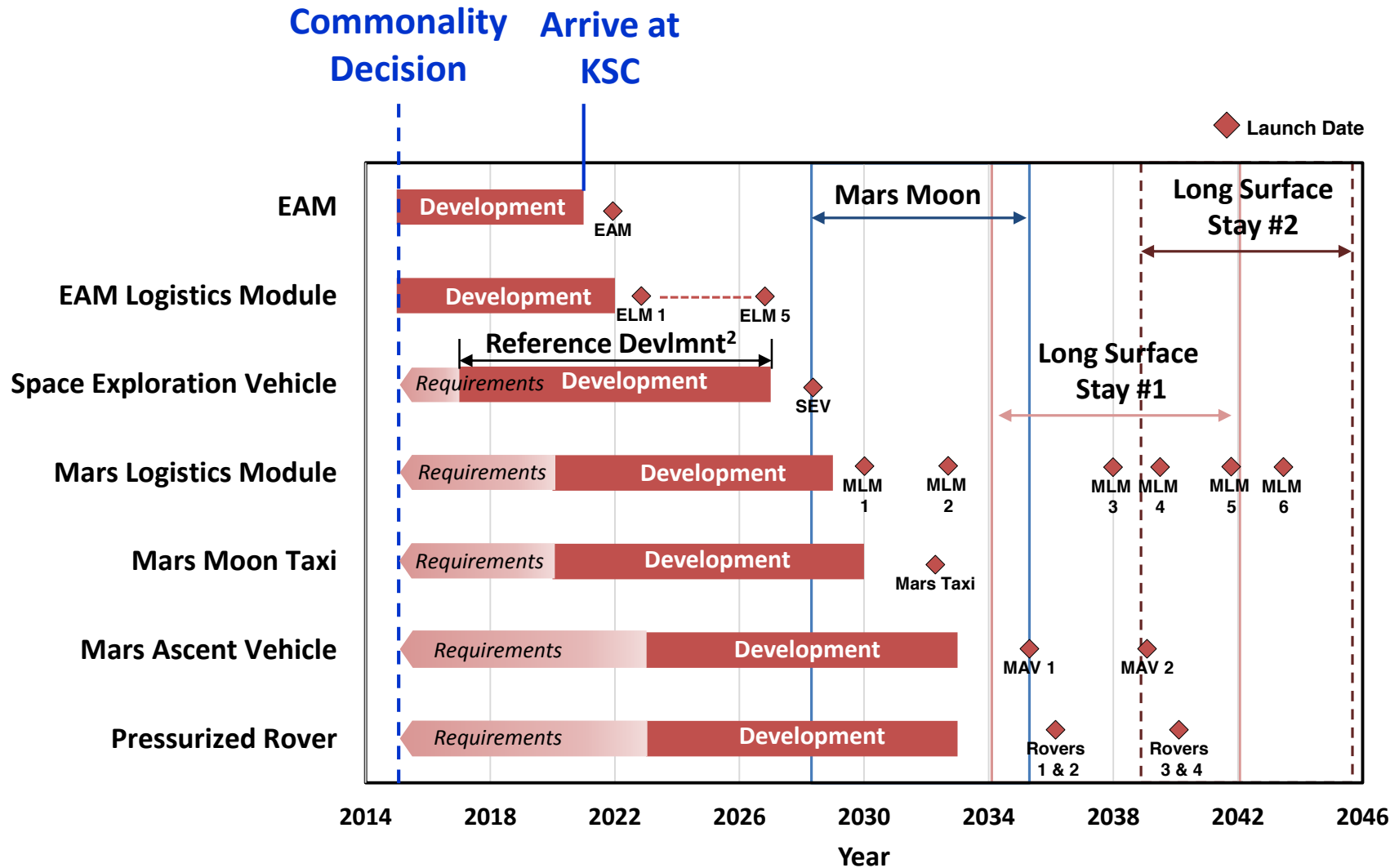
Lower Development Cost

Lower Operating Cost

Common cockpit type-rating allows crews to fly both 757 and 767

Development Schedule and Sequence¹

SEP/Chem



¹ Based on 1/28/15 EMC Manifest

² HEOMD Support to MPPG, Notional Development/Risk Reduction Schedule for a 2033 Human Mars Mission, July 2012

Number of EMC Small Habitats

SEP/Chem



Challenge: How to achieve commonality with few elements over many years

Mission Phase	Mars Ascent Vehicle (4 crew)	Mars Moon Taxi	Mars Moon Exploration Vehicle	Mars Rover	EAM	Logistics Module (EAM)	Logistics Module (Mars)	
Proving Ground					1	5		6
Phobos Mission		1	1				2	4
Mars Long Stay #1	1			2			2	5
Total	1	1	1	2	1	5	4	15
Mars Long Stay #2	1			2			2	5
Total	2	1	1	4	1	5	6	20

8 "Mars" Habs over 14 years

9 Habs over 20 years

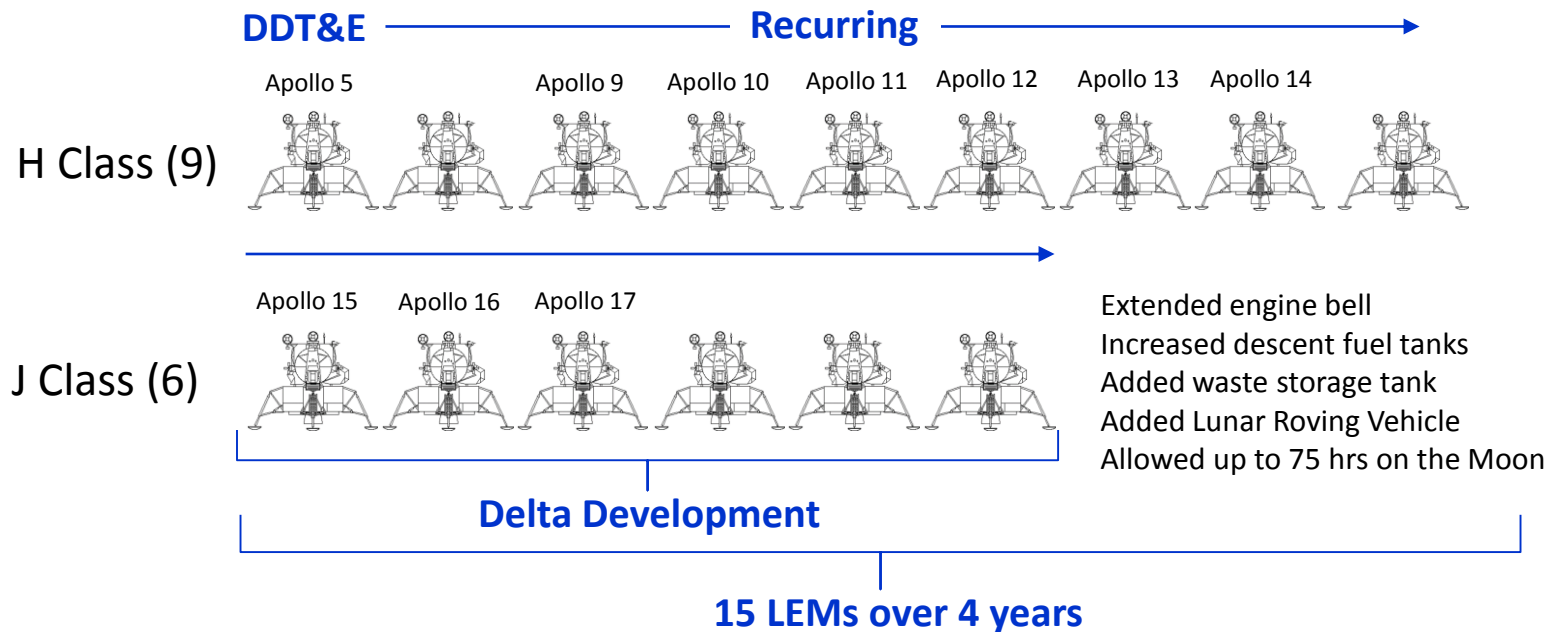
13 Logistics Modules

Note: Based on 1/28/15 EMC Manifest

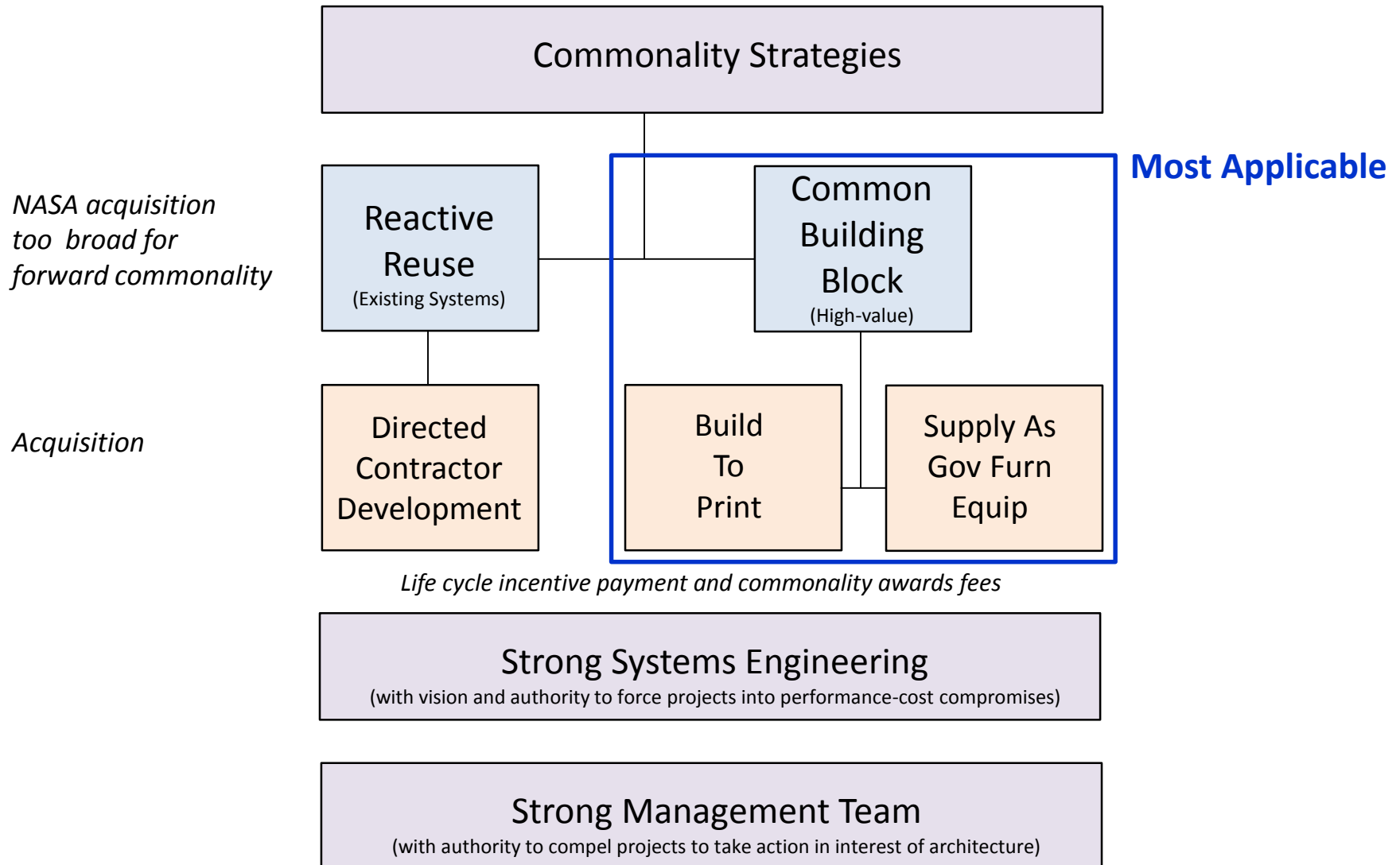
Example of Core Commonality



Apollo Lunar Excursion Module



Commonality Recommendations*

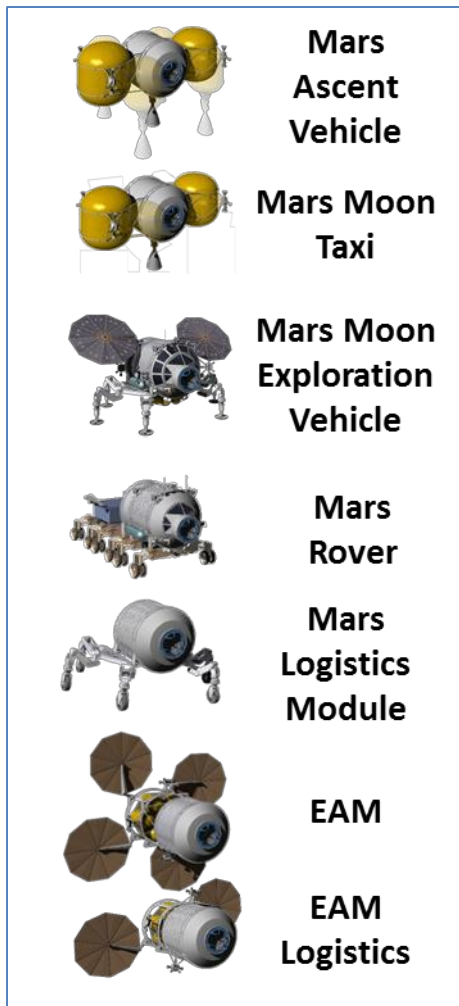


*Acquisition Strategies for Commonality Across Complex Aerospace Systems-of-Systems, A.C. Wicht, Master's Thesis, MIT, 2011

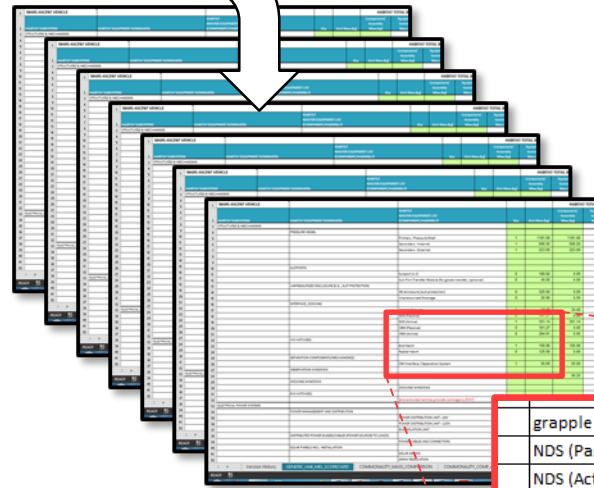


ANALYSIS TOOL

Small Habitat Master Equipment List



Habitats only



- Common MEL for each Hab
- Component / Subassembly level of detail
- Inclusive “superset” of component choices
- Component quantity specification controls content

grapple fixtures	1	34.40
NDS (Passive)	0	161.27
NDS (Active)	1	351.14
CBM (Passive)	0	161.27
CBM (Active)	0	264.81
End Hatch	1	105.06
Radial Hatch	0	125.00

• Other Input Features

- Geometry characteristics
- Component locations (In or Out of Hab)
- Data source references
- Notes and rationale

Commonality Scoring Process



- Assumes specific Common Core scenarios to assess level of commonality
- Index values provided to Costing Tool for each subsystem for a given Common Core scenario
- Index is fraction of equipment groups common to Core within subsystems (1.0=all equipment types are in core scenario)
- Currently modeling 3 scenarios:
 - Natural Commonality: No equip features forced, common functional needs
 - Full-Featured: All features forced, all values=1.0, highest mass impact
 - Build-Your-Own: All features are user-selected

Example Commonality Index Matrix (provided to LCC Tool)

Habitat Commonality Comparison CORE-A (Natural, "Across-the-Board")	COMMON CORE-A	MARS ASCENT VEHICLE (MAV)	MARS MOON TAXI	MARS MOON EXPLORATION VEHICLE	MARS ROVER	MARS LOGISTICS MODULE	EXPLORATION AUGMENTATION MODULE (EAM)	EAM LOGISTICS MODULE
COMPOSITE	0.52	0.50	0.50	0.50	0.50	0.50	0.50	0.50
STRUCTURES & MECHANISMS	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38
ELECTRICAL POWER SYSTEMS	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33
AVONICS	0.48	0.48	0.48	0.48	0.48	0.48	0.48	0.48
THERMAL CONTROL SYSTEMS	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
ENVIRONMENTAL PROTECTION	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
ENVIRONMENTAL & LIFE SUPPORT (ECLS) SYSTEMS	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60
CREW SYSTEMS	0.80	0.57	0.57	0.57	0.57	0.57	0.57	0.57
EVA SYSTEMS	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
RESEARCH & UTILIZATION SYSTEMS	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10

Mass Comparison Table



Subsystems				EMC Small Habitats				Common Core Options				Ref Habs				
	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
	Habitat Mass Comparison:				MARS ASCENT VEHICLE (MAV)	MARS MOON TAXI	MARS MOON EXPLORATION VEHICLE	MARS ROVER	MARS LOGISTICS MODULE	EXPLORATION AUGMENTATION MODULE (EAM)	EAM LOGISTICS MODULE	COMMON CORE-A Across-the-Board Features Only (Mass, kg)	COMMON CORE - B Full Featured (Mass, kg)	COMMON CORE - X BYO Commonality Features (Mass, kg)	REF MAV (ADDM #2)	REF MMSEV
1	Mass Comparison Totals (kg)				5071	6462	6550	5877	3572	8578	3303	5539	9452	6101	3653	4556
2	STRUCTURES & MECHANISMS				1800	1800	2217	2215	1750	1754	1750	1855	2267	1470	1700	2426
3	ELECTRICAL POWER SYSTEMS				761	1077	1077	376	491	2137	342	958	2137	1681	371	52
4	COMMAND & DATA HANDLING SYSTEMS				231	231	231	231	231	231	231	231	231	96	231	72
5	DISPLAYS, CONTROLS & LIGHTS				34	34	34	34	20	34	20	20	34	25	34	16
6	GUIDANCE & NAVIGATION SYSTEMS				75	75	75	75	0	75	0	0	75	53	75	13
7	COMMUNICATIONS & TRACKING SYSTEMS				82	82	82	82	0	82	0	0	82	6	82	143
8	THERMAL CONTROL SYSTEMS				604	484	336	381	350	484	230	604	604	407	249	387
9	ENVIRONMENTAL PROTECTION				415	415	415	415	415	415	415	415	415	0	0	221
10	ENVIR CTL & LIFE SUPPORT (ECLS) SYSTEMS				491	656	656	656	162	656	162	273	656	329	358	447
11	CREW SYSTEMS				416	212	262	262	54	1470	54	519	1697	1435	259	239
12	EVA SYSTEMS				0	830	560	544	0	576	0	0	579	504	77	299
13	SCIENCE SYSTEMS				0	0	0	0	0	0	0	0	0	0	0	7
14	SAMPLE COLLECTION SYSTEMS				11	0	0	0	0	0	0	0	11	11	14	0
15	CONSUMABLES				152	567	607	607	101	664	101	664	664	84	203	236
17																
18																
19																
20																

- Provides mass comparisons of Habitats at Subsystem level
- Compares potential Common Core options
- Lists Habitats from prior studies as reference (mapped to same subsystems)

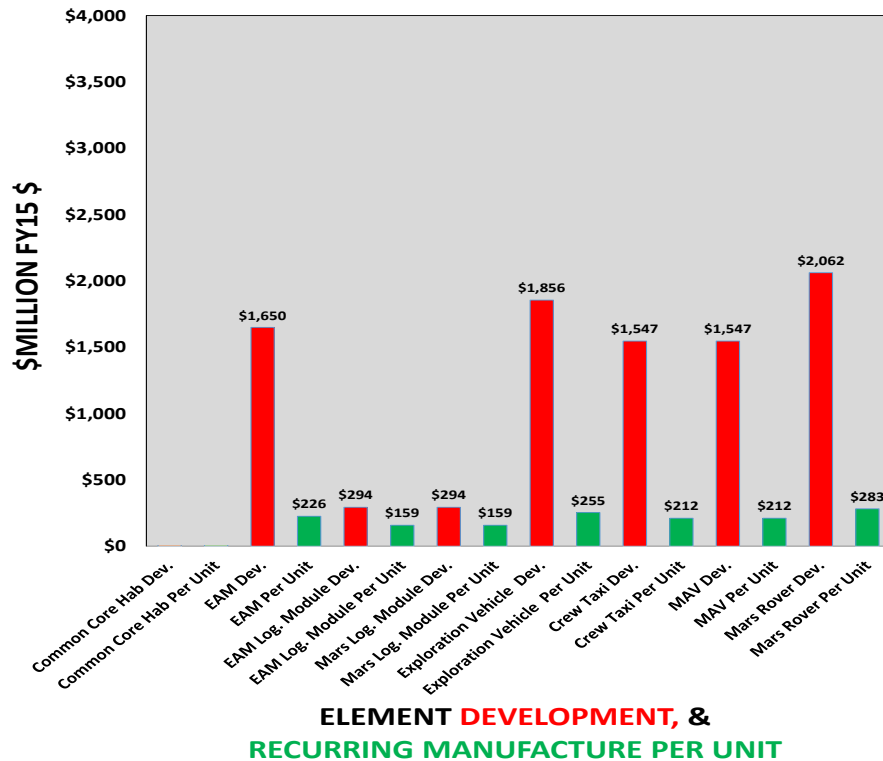
Overview – Commonality LCC Assessment

Results – Assessment as Modeled



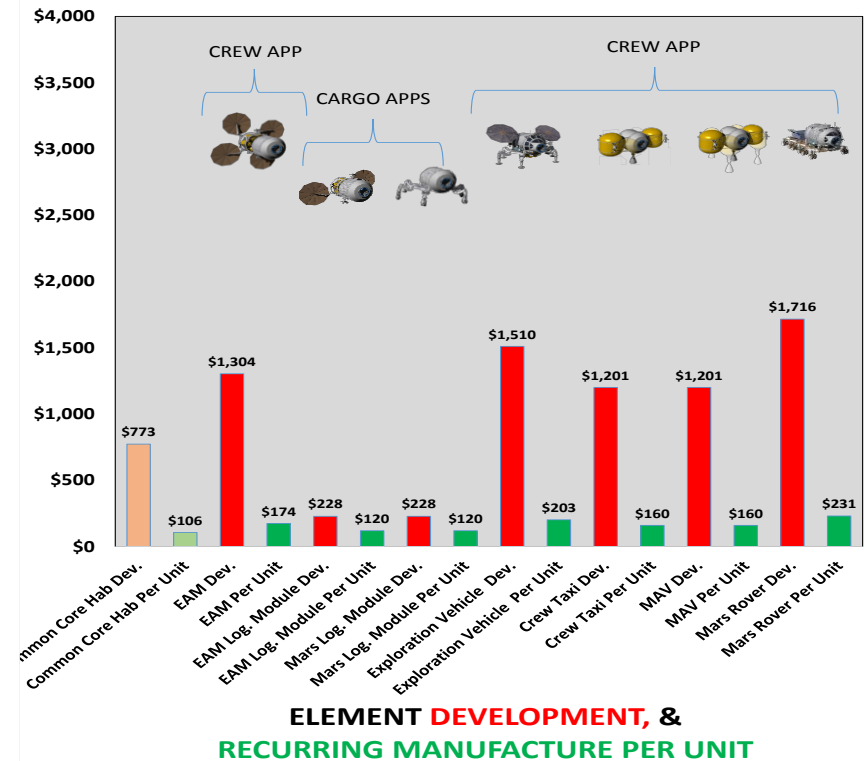
No Commonality

Element Costs with Commonality as Set
Small-Hab > Element 2 > Element N...



With Commonality per MEL

Element Costs with Commonality as Set
Small-Hab > Element 2 > Element N...



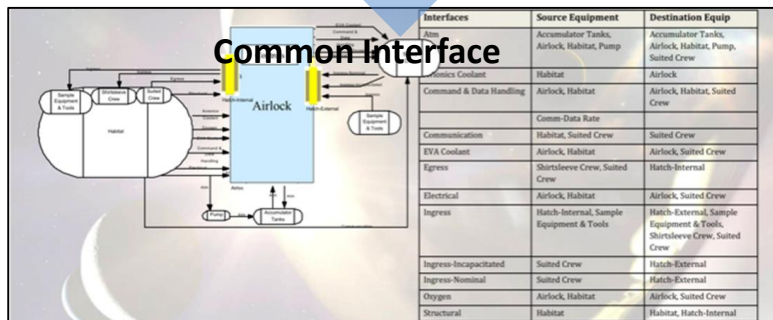
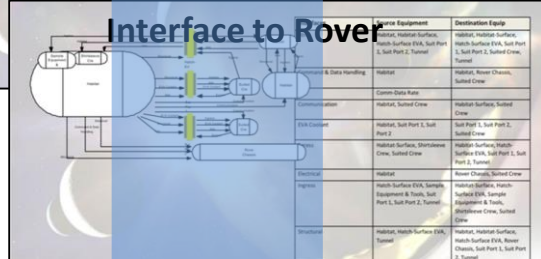
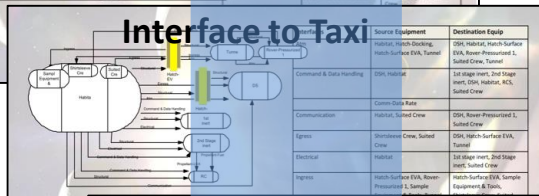
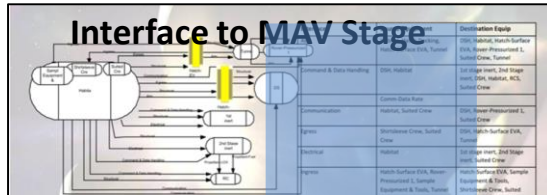


HABITAT CONFIGURATION

Common Interfaces and Structural Design



Small Habitat Interfaces



Acceleration Loads

Mission Phase	Acceleration Loads	Mars Ascent Vehicle	Mars Moon Taxi	Mars Moon Explor Vehicle	Mars Rover	EAM	EAM Log Mod	Mars Log Mod
SLS launch 1 – Transonic 2 – Max accel	1) 2.75 g's axial, 1.5 g's lateral ¹ 2) 5 g's axial, 0.25 g's lateral ²	Fuel Tanks Full	Fuel & Ox Tanks Full	X	X	X	X	X
Transit burns	0.5 g's axial	Fuel Tanks Full	Fuel & Ox Tanks Full	X	X			
Mars entry/descent	4.5 g's axial, 0.5 g's lateral ²	Fuel Tanks Full			X			X
Mars landing	2.75 m/s sink rate 1.0 m/s lateral ³	Fuel Tanks Full			X			
Mars ascent	1.3 g's ² axial, 0.5 g's lateral ⁴	Fuel & Ox Tanks Full						

MMOD Accommodations

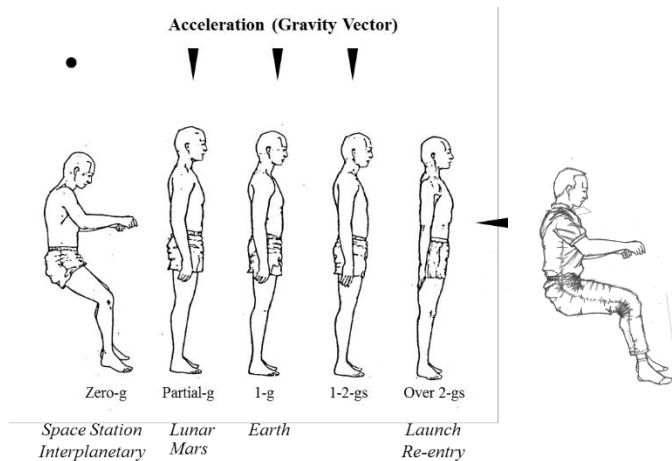
Element	Exposure Duration (Days)				Do We Need Shields?	Rationale
	Cis-Lunar Aggregation	Transit	Orbit	Surface		
EAM	-	365	270-300	-	Yes	Long exposure duration
Mars Transit Habitat	183	183	365-1095+	-	Yes	Near-Earth orbital debris exposure + long Mars orbit exposure
Phobos Taxi	183-365	365	365 - 548	-	Yes	Near-Earth orbital debris exposure + long Mars orbit exposure
Phobos Hab	-	365 - 1204	730	365-1095+	Yes	Very long exposure durations
Mars Surface Hab	-	1351	-	500+	Probably in transit	Trade shield mass vs. risk of repair in Mars orbit before landing
Mars Pressurized Rover	-	1351	-	500+	In transit	Depends on whether it's exposed or encapsulated in transit
Mars Ascent Vehicle	-	1351	-	730	In transit	Possibly remove shields for ascent, if ascent is short and MAV is not re-used

Duration times courtesy of K. Goodliff

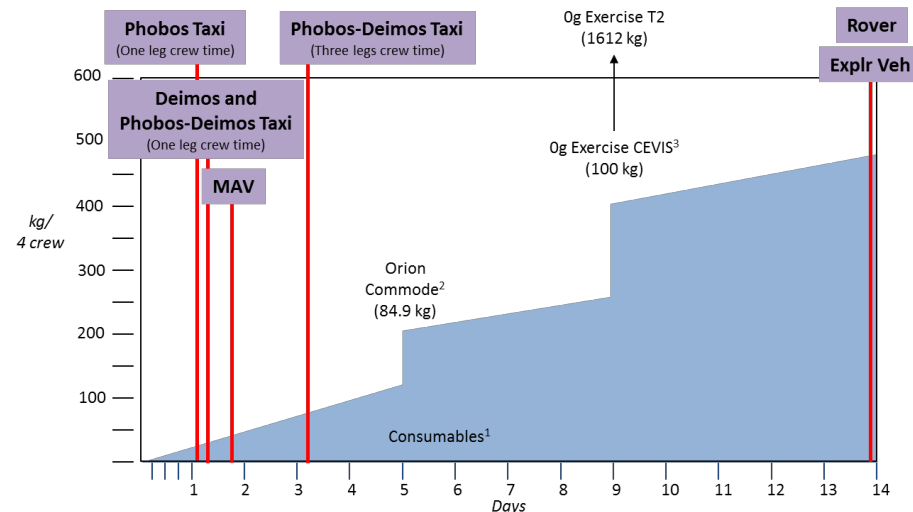
Design Accommodations



Weightless, Ascent/Descent, Surface



Mass per Excursion Duration



Different Operations Postures

	Variable g			Micro g		Mars g		Micro g	
Operation	Mars Ascent Vehicle (4 Crew)	Mars Moon Taxi	Mars Moon Exploration Vehicle	Mars Rover	Mars Logistics	EAM	EAM Logistics		
Displays and Controls							NA		
Window Viewing							NA		
Hatch Translation									
EMU don/doff	NA			NA	NA		NA		
Suitport ingress/egress	NA						NA		
Task Restraint									
Sleeping							NA		
Personal Hygiene							NA		
Maintenance Repair							NA		

■ NBP ■ Couch/reclined ■ Standing ■ Sitting ■ Crawling ■ Walking ■ Climbing ■ Lying Down

Suit Accommodation

	Mars Ascent Vehicle	Mars Moon Taxi	Mars Moon Exploration Vehicle	Mars Logistics	Mars Rover	Initial Habitation Module	Logistics
Transit Phase							
Launch		If crew lands in taxi travel to Mars Transit Vehicle (MTCV) and 4 MACEs	2 support, umbilical, EVA suits and support sys	2 support, umbilical, EVA suits and support sys	If crew lands in rovers: 2 support, umbilical, EVA suits and support sys	Airlock support, port, bilicals, EVA c	EVA c
DRO staging						2-4 EVA suits and support sys	EVA c
Transit/outbound						NA	NA
Mars Orbit	NA	Transfer 4 EVA suits and support sys (that go on support sys)	2 support, umbilical, EVA suits and support sys	2 support, umbilical, EVA suits and support sys	2-4 EVA suits and support sys	NA	NA
EDL		NA				NA	NA
Surface		NA				NA	NA
Ascent	Transfer 4 MACEs, umbilical, and support sys	NA	NA	NA	NA	NA	NA
Transit/return*	NA	NA	NA	NA	NA	NA	EVA c
DRO*	NA	NA	NA	NA	NA	EVA c	EVA c
Earth Entry*	NA	NA	NA	NA	NA	NA	NA

2 EVA suits are always on Mars Transfer Vehicle

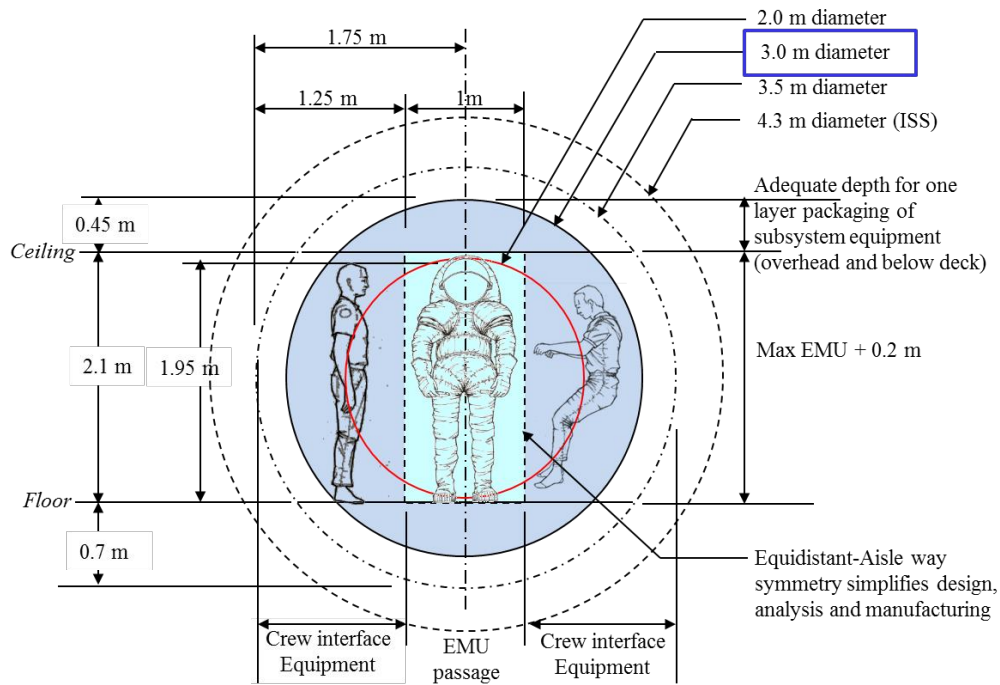
*MACEs for Transit/return, DRO, and Earth Entry on Mars Transfer Vehicle

■ MACEs ■ Og EVA ■ Mars EVA ■ Mars Spares ■ Logistics 19

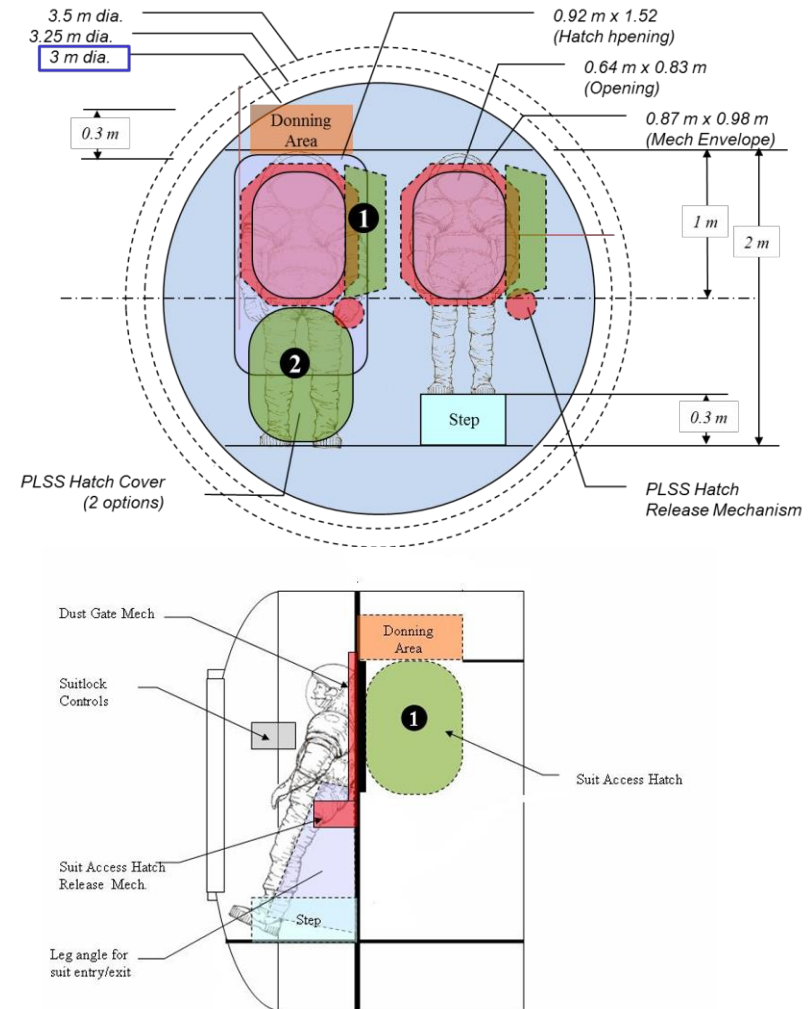
Selecting a Diameter



Crew Anthropometry and Equipment Location



Suitport End Dome



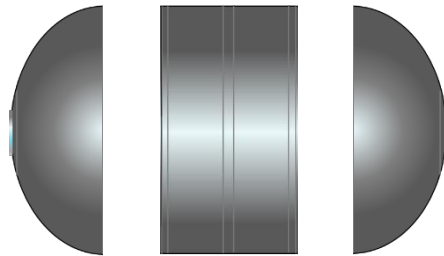
Selecting a Pressure Vessel

Orientation wrt acceleration vector

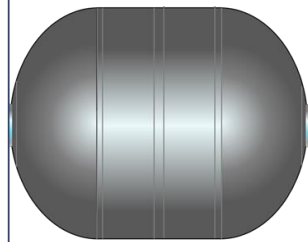


Geometry (Starting Point)

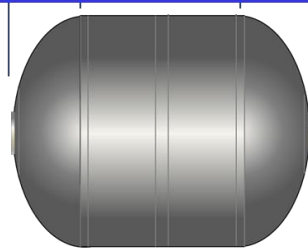
End-dome Cylinder End-dome



Fixed Length

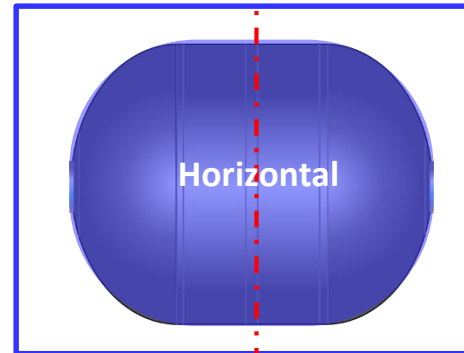
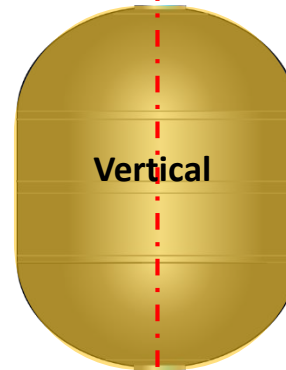


Longer Barrel



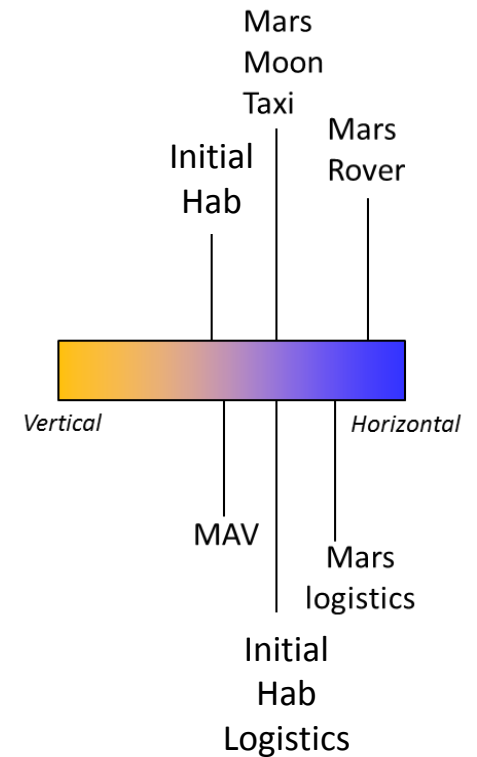
Preferred

Acceleration



Preferred

Orientation Preference



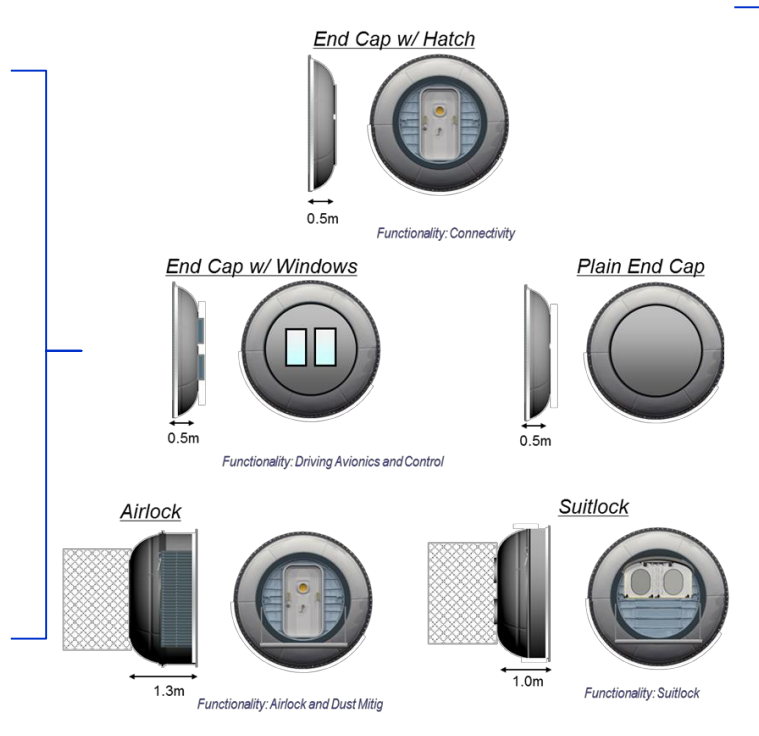
Bulkhead Tailoring



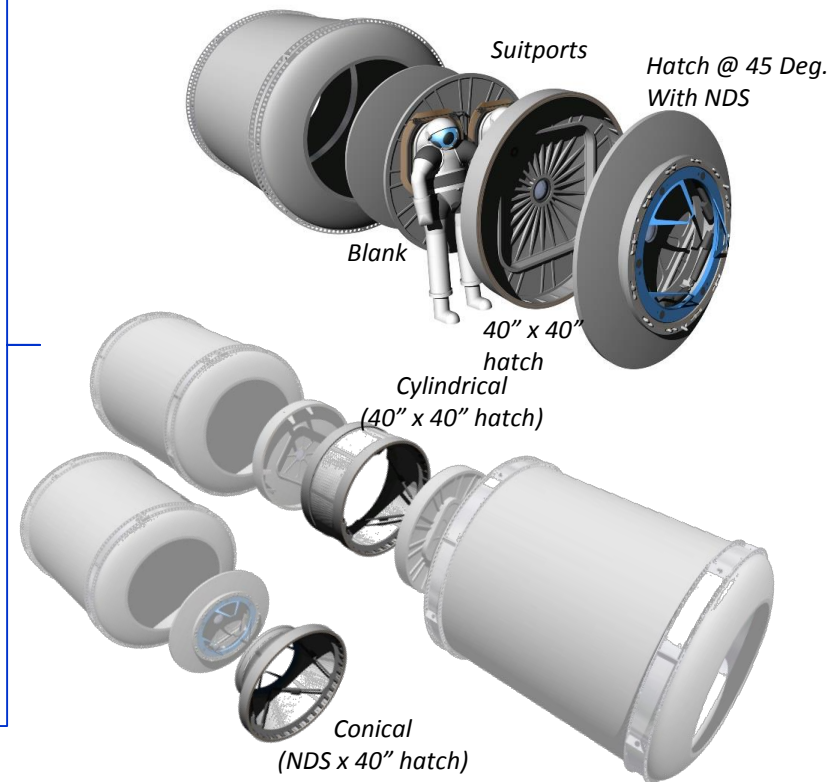
Core Structure



Tailored End Dome



End Domes and Adaptors



Small Cabin Common Pressure Vessel



“Intermodal” common interface ring

Load path support fixture at quarter points

Power socket

Features

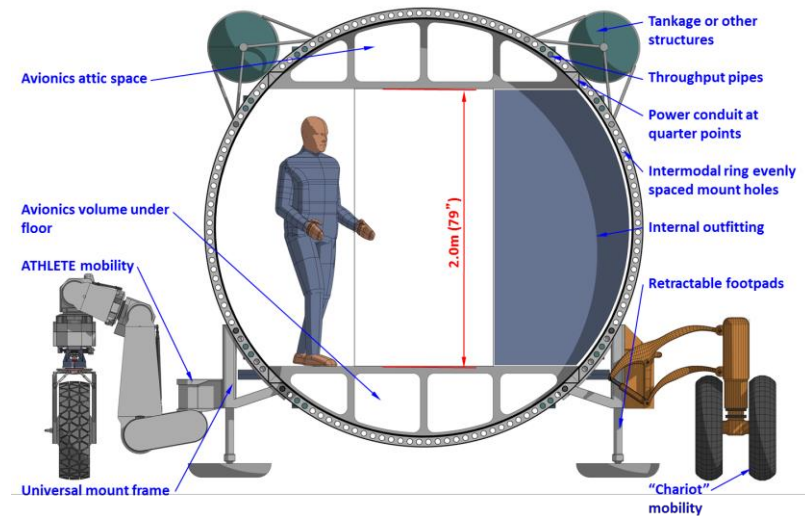
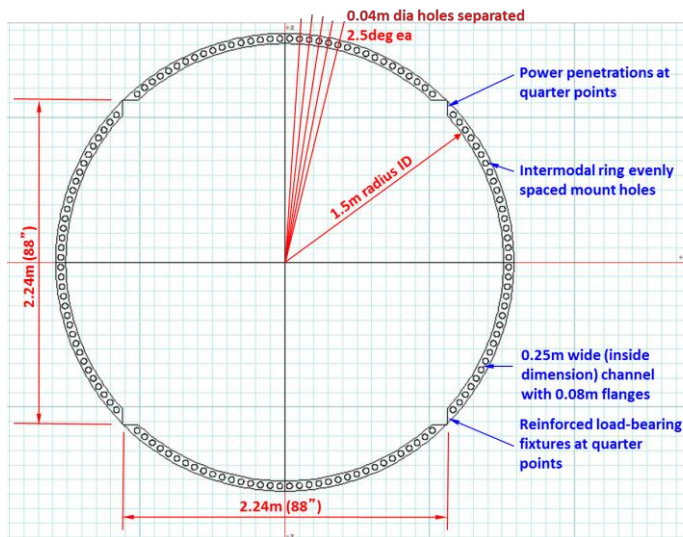
Barrel with isogrid

End cone

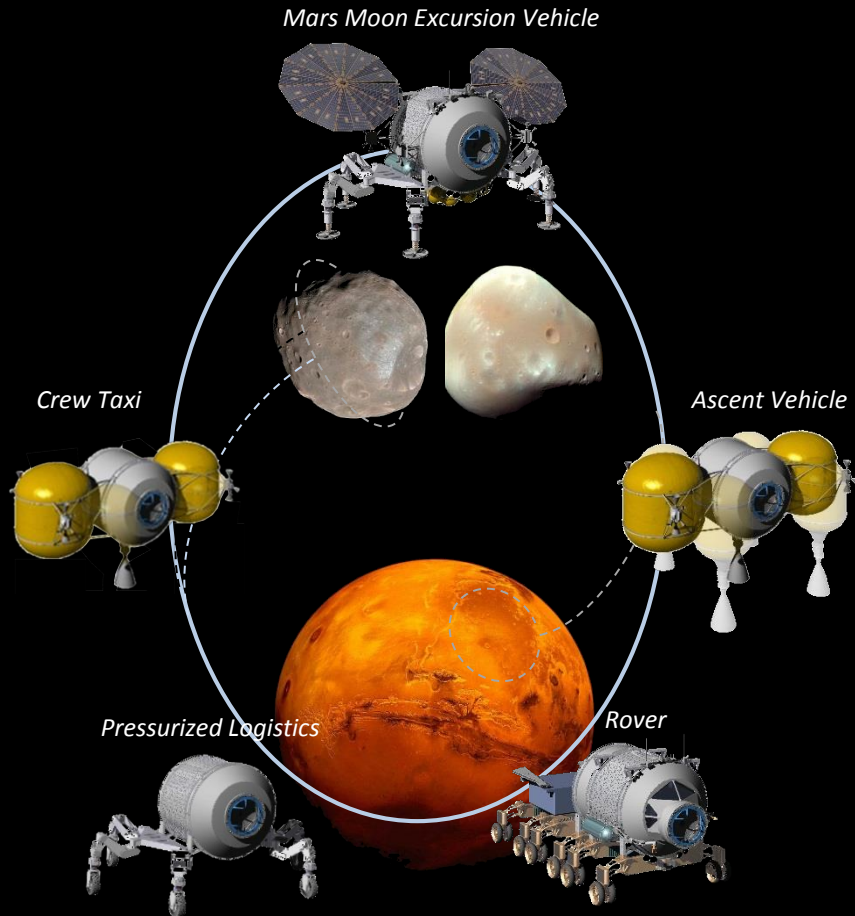
Swappable bulkhead

Strawman Sizing

Internal/External Accommodations



Notional Representation of Common Small Habitats



Initial Habitation Module

Pressurized Logistics

